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A REVIEW: ROLE OF PLANT GROWTH REGULATORS IN VEGETABLE PRODUCTION

OM PRAKASH MEENA

Department of Vegetable Science, Punjab Agricultural University, Ludhiana, Punjab, India

ABSTRACT

Plants control their physiological programmes, developmental transitions and responses to the environment with the help of phytohormones/ plant growth regulators. These are organic compounds of varied chemical structure synthesized by plants in low concentrations in specialized tissues and transported throughout the plant body where they alter essential physiological processes qualitatively and quantitatively. The main groups of plant hormones include auxins, gibberellins, cytokinins, abscisic acid, ethylene, brassinosteroids and jasmonates. Phytohormones have multiple functions and various combinations of them can act either synergistically (auxins and gibberellins) or antagonistically (abscisic acid and auxins) to promote very specific responses.

KEYWORDS: PGRS, Production, Vegetables

INTRODUCTION

Hormone is a Greek word derived from hormao (Upu w) which means to urge on or to stimulate (Beylis and Starling, 1902). Thimann (1948) suggested using of the term phytohormone for hormones of plants. A plant hormone is an organic compound synthesized in one part of a plant and translocate to another part where in very low concentration, it causes a physiological response. To distinguish it from animal hormone, it was termed as phytohormone. Similarly Phillip (1971) defined growth hormone as substances which are synthesized in particular cells and are transferred to other cells where in extremely small quantities influence the developmental process. However, the term hormone is quite popular and widely used.

There are mainly five categories of hormones (Table 1) namely auxins (derivatives of the indole-3-acetic acid), gibberellins (tetracyclic carbonic acids of the diterpenoid class-GA_3), cytokinins (derivatives of 6-aminopurine-zeatin), abscisic acid (abscisic acid ABA-a sesquiterpenoid with optical activity) and ethylene (colorless gas, unsaturated hydrocarbon with a double bond). A plant tissue may contain more than one of these growth regulators at the same time. The leaf primordial and developing seeds contain both auxin and gibberellins and in some plants ABA also. Both auxins and gibberellins cause stem elongation by different mechanisms while ABA and ethylene inhibits stem growth. Thus, two or more growth regulators may be similar in their action. When the effect is more than the sum of their individual effects it is called synergistic and when the action of two growth regulators is opposite it is called antagonistic. The final growth and development of the plant is the sum of total interactions of different growth regulators that are present in the plant.

Table 1: Principal Groups of Phytohormones

Hormone	Synthesis Location	Target Tissue
Auxins	Stem apex, developing fruits	Primary cell wall
Giberelline	Immature seeds	Internodes, seeds, fruits
Cytokinin	Actively growing regions	Roots, stem, phloem, xylem
Abscisic acid	Leaves	Stomata
Ethylene	Fruits, flowers, leaves, roots	Buds, seeds, fruits

Natural and synthetic substances that act as growth regulators, according to the mode of action, are divided into (Figure 1): growth promoters; growth inhibitors; retardants (only synthetic).

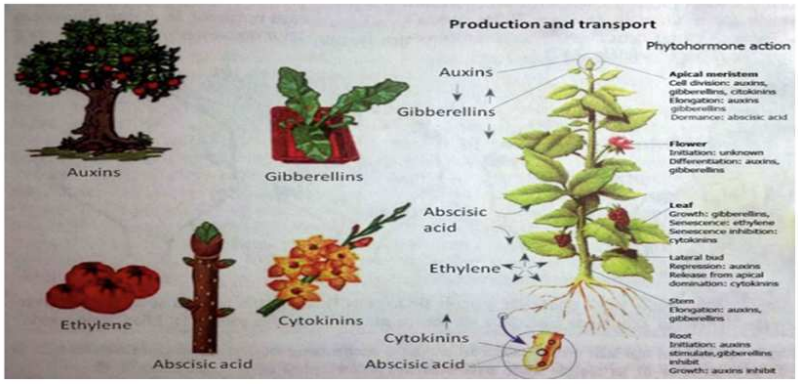

Figure 1: Differential Effects of Phytohormones on Life Processes in Plants (Source: Duca, 2015)

Auxins, gibberellins and cytokinins are considered stimulants and abscisins and ethylene-inhibitory hormones. There are multiple links between them, they have a versatile action, which depends, on one hand, on the concentration of the hormone that has reached the target cells, on the other hand, on the tissue competence (ability to respond, type and intensity of the response) (Figure 2). These three groups of substances are not acting separately. They interact in such a manner that all stages of growth and development are the result of equilibrium between stimulators and inhibitors that manifest mainly in seasonal processes.

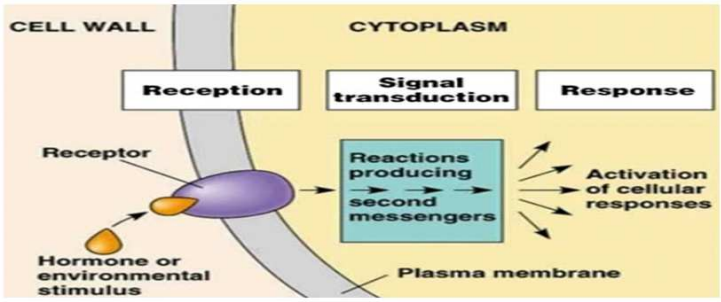

Figure 2: Induction of the Hormonal Response by Hormonal or Environmental Factors (Source: Duca, 2015)

AUXINS

The very existence of growth substances was proposed by Charles Darwin (1880) in his book *The Power of Movements in Plants*. Most of knowledge about auxins comes from the work on oat (*Avena sativa*) coleoptile. The first higher plant from which auxin could be extracted was maize kernels. It was identified as IAA. Indole Acetic Acid (IAA) is the principal naturally occurring auxin of all higher plants and fungi.

Biosynthesis: The auxin precursor in plants is tryptophan or substances derived from its degradation. It is formed by following three steps involving three enzymes: transaminase, which catalyzes the conversion of tryptophan into tryptamine, decarboxylase-from tryptamine to indole pyruvic acid, which transforms into β- indole acetaldehyde and aldehyde dehydrogenase, which catalyzes the formation of β-indole acetic acid. All the parts of the plant body produce auxin. However, the major sites of auxin production are the shoot tips, developing seeds and buds.

Synthetic Auxins: There are a number of synthetic chemicals which are similar to IAA in their biological activity. However, they do not occur in any plant. The important synthetic auxins are IBA (IndoleButeric Acid), NAA (αand β-Naphthalene Acetic Acid), 2, 4-D (2, 4-dichlorophenoxyacetic acid), 2, 4, 5-T (2, 4, 5-trichlorophenoxyacetic acid), IPA (Indole Propionic Acid), naphthoxyacetic acid etc.

Functions of Auxins: Auxins have been used variously and some of the aspects are as follows: (i) it causes cell elongation by loosening of the cell wall, (ii) promotes secondary growth of stem through cambium activity, (iii) promotes callus and root formation in cutting, (iv) restores apical dominance, (v) induction of flowering, (vi) increases fruit setting and size, (vii) delays leaf abscission, (viii) prevention of premature drop of fruits, (ix) develops parthenocarpic fruits, (xi) acts as herbicide at higher concentration, (xii) inhibition of prolonged dormancy, and (xiii) inhibiting aging processes in tissues.

GIBBERELLINS

Gibberellins are the second important growth hormones found in plants. Gibberellin was first known by a Japanese farmer Konishi (1898) but Kurosawa working in Farmosa discovered GA in 1926. It was first extracted from the ascomycetous fungus *Gibberellafujikuroi*(*Fusariummoniliforme*), the causal organism of "*foolish seedling of rice*" or commonly called *bakanae disease of rice*. The infected plants were usually taller, seedless and pale in colour. He applied the fungal extracts to intact healthy plants and observed enhanced growth. Later, Yabuta and Sumuki (1938) named the active principle as 'gibberellin'. Further it was purified, crystallized and named as 'gibberellic acid' (Curtis and Cross, 1954). Now gibberellins are designated as GA_1, GA_2 and so on. The common gibberellic acid is GA_3. At present 112 types of gibberellins are known.

Biosynthesis: Gibberellin predecessor is kaurene. In the chemical structure of both of them there is a common backbone-gibban, to which certain side groups are attached that determines their specificity. Thus each plant species has its own set of gibberellins. Gibberellins are synthesized in the young leaves (major site), shoot tip, root tip and immature seeds (embryo).

Function of Gibberellins: GA finds application in a variety of ways, some of them are discussed here: (i) it induces maleness, (ii) promotes growth of dwarf plants, (iii) possesses pollenicide effect, (iv) replaces chilling and light requirements of plants, (v) promotes seed germination, (vi) used for breaking of dormancy, (vii) delays senescence of fruits, (viii) enhances seedless fruits, (ix) for stem elongation, (x) accelerates flowering in long day plants, and (xi) intensifies transpiration, photosynthesis and respiration.

CYTOKININS

Cytokinins play a key role in the life of higher plants. Skoog (1955) has demonstrated that when pith tissues of *Nicotianatabacum* were separated from vascular and cortical elements, they grew similar to auxin containing medium and

showed enormous enlargement without cell division. If vascular tissues were placed in contact with them, pith tissue resumed cell division. This observation proved instrumental in the discovery of cytokinins. Millar, Skoog, Saltza and Strong (1955) isolated a substance from herring sperm-DNA and named it *kinetin*. This liquid endosperm of coconut (coconut milk) is also found to be rich in cell division causing factors. Letham (1963) extracted, purified and crystallized cytokinin from immature kernel of maize and named it as *zeatin*. Functional activity of cytokinins occurs in the presence of auxins.

Biosynthesis: Zeatin is synthesized from mevalonic acid and adenine. Usually *Zeatin* is the most abundant naturally occurring free cytokinin. It was found that cytokinins are the result of degradation of nucleic acids and therefore, could serve as an indicator of the rate of DNA replication. In plants cytokinins exist in free and bound form. Bound cytokinins are synthesized in the cytoplasm and chloroplasts. It is assumed that they may be synthesized also in mitochondria based on their own DNA. This confirms the endosymbiotic theory organelle genesis. Root tip is an important site of cytokinin synthesis. However, developing seeds and cambial tissues are also the site of its biosynthesis.

Synthetic Cytokinins: Several substances have been found showing cytokinins like activities. The common examples are 6-aminopurine (adenine), benzimadazole, 6-benzyladenine, 1-benzyladenine etc.

Function of Cytokinins: Some important roles of cytokinins are as follows: (i) it promotes seed germination and radical growth by breaking dormancy, (ii) it helps in cotyledon expansion in immature seedling of dicots, (iii) it stimulates chlorophyll synthesis, (iv) it induces cell division and shoots development, (v) it delayed senescence of leaves, (vi) nucleic acid metabolism, (vii) protein synthesis, and (viii) it incorporation in RNA.

ABSCISSIC ACID (ABA)

The plant growth regulator ABA is one of the wide spread and naturally occurring inhibitor found in plants. It was for the first time identified by Wareing (1965) in *Acer pseudoplatanus* leaves and buds who gave the name *dormin* to it. Addicot and his colleagues (1963) isolated this abscission causing compound from cotton bolls and named it as abscisin I and abscisin II but in 1967, a common name *abscissic acid* was given to both. ABA is known as dormancy inducing and abscission accelerating substance. ABA has been reported to inhibit mRNA and protein synthesis. ABA is found in all parts of the seed namely the seed coat, embryonic axis, cotyledons and endosperm.

Biosynthesis: Is synthesized in mature leaves and fruits. ABA biosynthesis occurs via two pathways.

- from mevalonic acid → isopentenyl pyrophosphate → heranylpirophosphate;
- by carotenoid and violaxanthine decomposition → xanthoxin → abscisic acid.

It was found that induction of ABA synthesis occurs during genome reprogramming and synthesis of increased amounts of ABA-inducing polypeptides, of which lectins are more significant.

Function of ABA: Some important roles of ABA are as follows: (i) it cause stomatal closure in response to water stress, (ii) it inhibits cell wall loosening, (iii) it inhibits viviparous germination of the developing embryo, (iv) it enhances tuberization, (v) it accelerated senescence of leaves and fruits, (vi) accumulates sucrose in seeds, sweet fruits, reserve tissues of the roots, and (vii) has anti-gibberellin, anti-auxin, anti-quinine action.

ETHYLENE (THE RIPENING HORMONE)

Neljubow (1901) a Russian plant physiologist was the first to show the importance of ethylene present in the illuminating gas as a growth regulator of plants. He observed that dark grown pea seed lings growing in the laboratory (illuminated with coal gas) exhibited symptoms that were later termed as *triple response*: reduced stem elongation, increased lateral growth, and abnormal horizontal growth. Denny (1924) reported that ethylene is highly effective in inducing fruit ripening. Ultimately Gane (1934) established that ethylene is actually a natural product of ripening fruits. It acts upon DNA, RNA and protein biosynthesis, induction and modification of endospermic reticulum.Auxins increased ethylene level in plants and many of auxin actions are attributed through ethylene such as increased percentage of female flowers, apical bud dominance and leaf epinasty.

Biosynthesis: In higher plants, all most the parts of the plant body produce ethylene. In general meristematic region and nodal regions are most active in ethylene biosynthesis. However, ethylene production also increases during leaf abscission and flower senescence, as well as during fruit ripening. This is otherwise called as phytogerontological hormone. Very little is known about its synthesis inside the plants but it appears that methionine (an amino acid) may be an immediate precursor of ethylene. ACC (aminocyclopropane carboxylic acid) is the penultimate precursor of ethylene.

Synthetic Ethylene: Ethepon, ethrel, cepha etc.

Function of Ethylene: Following are some important roles: (i) ethylene acts as soil fungistasis, (ii) it hastens abscission of plants, (iii) it encourages root formation, (iv) it acts as a fruit ripening hormone, (v) it enhances seed germination, (vi) it induces production of female flowers, (vii) it induces male sterility, and (viii) it inhibits vegetative growth and triggers reproductive growth.

GROWTH INHIBITORS: These are substances which suppress the growth of plants.

- **Phenolic Inhibitors:** Benzoic acid, salicylic acid, cinnamic acid, caffeic acid, ferulic acid, coumarin, juglone, scopoletin, naringenin, chologenic acid.
- **Synthetic Inhibitors:** Maleic hydrazide, TIBA.

Functions: Following are some important roles: (i) it accelerates degreening, (ii) it induces abscission, (iii) it suppresses the vegetative growth and induce flowering, (iv) it induces sterility, and (v) it increases diseases resistance, salt tolerance and resistance to low temperature.

GROWTH RETARDANTS

These are diverse groups of chemical having common physiological effect of reducing stem growth by inhibiting cell division of the sub-apical meristem. The formation of leaves, flowers and fruits remain unaffected. Growth retardation is primarily induced by inhibition of gibberellin biosynthesis between ent-kaurene and ent-kaurenoic acid. The important growth retardants are uniconazole, paclobutrazole (P_{333}, Cultar), triapenthenol, flurpirimidol, inabefide, AMO-1618, CCC, Phosphon-D, C-111, B_9, B_2, 4-DNC. **Functions:** Following are some important roles: (i) it retards stem elongation, (ii) it prevents cell division, (iii) it accelerates flower initiation, (iv) it inhibits root development, (v) it increases IAA oxidase activity, (vi) it inhibits staminate flower production, (vii) it block the synthesis of gibberellins, and (viii) it increases resistance to salt tolerance, drought resistance and pest resistance.

Table 2: Differences between Growth Inhibitor and Growth Retardant

Growth Inhibitor	Growth Retardant
Growth inhibitors inhibit the transport of auxins	Growth retardants inhibit the biosynthesis of gibberellins
Those are also called as anti-auxins or auxin-antagonists	Those are called as anti-gibberellins or gibberellins-antagonists
Growth inhibitors inhibit all growth processes permanently and promote abscission and senescence in plant	Growth retardants inhibit only some growth and physiological processes temporarily and its effect is overcome after sometime
They may be synthetic as well as natural	They are synthetic only

OTHER PLANT GROWTH REGULATORS

Brassinolides (Syn. Brassinosteroids or Terpenoids)

Brassinolides are a plant steroid discovered in pollen of member of the mustard family. The have been studied in *Arabadopsis*. Brassinolides represent a new sixth class of plant hormones with wide occurrences in the plant kingdom in addition to auxins, gibberellins, cytokinins, abscisic acid and ethylene. The substances from various pollen sources named 'brassins' a steroidal lactone, termed brssinolide, was first time isolated from pollen of *Brassica napus* by Grove and his associates in 1979. The first brassinosteroids-biosynthesis inhibitor named brassinazole, was first time reported by Asami and Yoshida (1999). Generally, pollen and immature seeds are rich source of brassinolide (with ranges of 1-100 ng g^{-1} fresh weight), while the concentrations in vegetative tissues are very low compared to those of other plant hormones. The functions of brassinosteroids analogous to that caused nyauxins and gibberellins such as stem elongation and plant morphogenesis. Therefore, it is difficult to study the brassinolides because their effects overlap those of auxins and gibberellins. Brassinosteroids activate signal transduction pathway that promote cell elongation and cell division.

Brassinosteroids control a broad range of responses in plant, including seed germination, stem and root elongation, vascular differentiation, leaf expansion and apical dominance. Interestingly, each of these responses is also controlled by auxins, suggesting there might be considerable interplay between these two hormones in the control of development. In addition to their role in plant development, brassinosteroids have the ability to protect plants from various environmental stresses, including drought, extreme temperatures, heavy metals, herbicidal injury and salinity.

Jasmonates (Jasmonic Acid)

Jasmonates are a group of fatty acid derivatives. They appear to have a role in seed germination, root growth and the storage of protein (especially in seeds). In 1990, airborne jasmonic acid methyl ester (JAME) was shown to induce proteinase inhibitors in tomato, thereby attributing to an 'immunization' against herbivore attack. Jasmonic acid and JAME are lipid-derived signals. Jasmonic acid and its related compounds are short-chain alkylcyclopentanone or alkylcyclopentane carboxylic acids and their derivatives. It is recognized as a new type of plant growth regulator. It widely occurs in the plant kingdom together with abscisic acid like physiological activities at low concentrations.

COMMERCIAL APPLICATION OF PGRS IN VEGETABLE CROPS

Tomato

Use of plant growth regulator in tomato has been found beneficial for yield, quality, earliness, cold and high temperature fruit setting and to develop resistance to TLCV. Soaking of seeds before sowing in GA_3 (0.5 ppm) or 2,4-D (0.5 ppm) enhances the germination of seeds. Seed treatment with B-napthoxy-acetic acid (BNOA) at 25-50ppm, Gibberellicacid (GA_3) at 5-20ppm and Chlorophenoxy acetic acid at 10-20ppm were reported to improve in growth and yield of tomato. Seedlings soaked for 24 hours in NAA at 0.1ppm showed higher fruit set and increased early and total yield. Foliar application of GA_3 at 10ppm, NAA at 1,000ppm, PCPA at 50ppm, 2,4-D at 0.5ppm or cytozyme at 1.25% were reported to increase in fruit yield. Spraying of PCPA at 50ppm, IAA 50ppm or borax 1% gave better fruit set in summer. The foliar application of PCPA (50-100ppm) at the flowering stage increases the fruit set at low and high temperatures. Cycocel (500 ppm) and GA_3 (25 ppm) have been found effective for overcoming damage caused by frost. Tomato plants sprayed with CCC at 0.4-0.5% appreciably increases the cold hardiness. Foliar spray of CCC (200ppm), ethephon(250ppm), paclobutrazol(40-150ppm) and mixtallol(2.0ppm) were reported to increases fruit yield. Seed treatment with 2,4-D @ 2-5ppm gives early fruit set and leads to parthenocarpy. The application of CCC (500ppm) on the plants in nursery 3-4 days before transplanting and other spray of it at 25-30 days after transplanting reduces the incidence of leaf curl disease and increases the early and total yield. Spraying is effective in determinate varieties having high degree of synchronization in flowering. The spraying at flower cluster is more useful, since the growth of the plant is not affected adversely. MH at 100-500 ppm is very effective for induction of male sterility. Ethrel treatments of harvested fruits enhance the ripening. In order to enhance the ripening of fruits, ethrel 1,000ppm can be sprayed on the plants at the time of initiation of ripening. An early spray may damage the foliage and reduce the size of fruits.Tomato fruit dipping in solution of GA_3 (100-500 ppm) retards the ripening and extends the storage life. Application of GA_3 at the time of flowering elongates the stigmatic position of flower and avoids selfing. Such lines can be used as female line in hybrid seed production programme. Application of Cycocel at 5-12 mg a.i./plant as soil application or as foliar spray at 0.1-0.3% improves considerable tolerance to salinity however, no reduction in uptake of salt could be noticed.

Brinjal (Eggplant)

Beneficial effect of growth substances on fruit-set in brinjal have been reported by several workers. Application of 2,4-D 2.0 ppm at flowering induces parthenocarpy, increases fruit-set, advances fruit maturation and significantly increases the total yield. Soaking of seeds for 24 h in GA_3 at 10-40 ppm improve germination. A significant increase in yield (50%) was obtained by whole plant spray of 2,4-D at 2ppm at intervals of one week over a period of 60-70 days from commencement of flowering. Spraying of 2,4-D (2.5ppm), 4 CPA (20ppm) and n-metatolylphthalamic acid (0.5%) promotes fruit set in brinjal. NAA 60ppm alone or in combination with BA 30ppm applied on open flowers improved fruit set and their development and spraying of n-metatolylphthalamic acid at 250-500ppm considerably increases the early yield. Root dipping of one month old seedlings in ascorbic acid, GA_3, IAA and thiourea advances the flowering by 4-5 days. Higher yield was obtained from plants whose roots were dipped in GA_3 and ascorbic acid each at 250ppm solution. MH at 100-500 ppm is very effective for induction of male sterility.

Chilli and Capsicum

Chilli plant growth is known to be improved by spraying of different growth regulators. Among several growth regulators available in the market application of CCC or cycocel10 days after transplanting, NAA (planofix) at flowering

had the most beneficial effect on plant growth. 10ppm of Planofix at flowering and three weeks later in chilli cultivars increased the number of branches. Chilli plant height was decreased but branching increased with application of Ethrel(300-500ppm) and CCC (500-2000ppm). Fruit set in chilli can be improved by application of growth regulators like GA_3 (10-100ppm), NAA (20-200ppm) and CCC (1,000ppm). MH at 100-500 ppm is very effective for induction of male sterility. Foliar spray of Triacontanol (1-2 ppm) improve the fruit set and reduces the flower and fruit drop at high temperature condition.

Potato

Soaking of potato seed tuber in CCC at 500mg/liter, sodium ascorbate at 100mg/l, cytozyme at 5% or foliar sprays with ethephon at 400mg/l, CCC at 25mg/l or gallic acid at 10-100mg/l increased tuber yield.Vapour treatment of potato tuber in ethylene chlorohydrin at 50 ml/q tubers followed by dipping in thiourea (1%) and finally in GA_3 (1 ppm) has been reported to break the dormancy. Spraying of potato haulms with 0.74 kg/ha of CCC causes a short term retardation of growth, stimulates the root growth and increases resistance of plant to frost.

Okra

Plant growth regulators affect okra in many ways, such as seed treatment by GA (400ppm), IAA (20ppm) or NAA (20ppm) enhanced germination; Ethephon (100-500ppm) reduced vegetative growth and weakened apical dominance; cycocel (1,000-1,500ppm) reduced plant height. Pod yield in okra is improved by soaking of seeds in GA_3 (50-100 ppm) or IAA (100 ppm). Foliar spray of Ethephon (250 ppm) or CCC (25 ppm) or NAA (15 ppm) at pre-anthesis also enhances pod yield. Post-harvest treatment with cycocel (100ppm) enhanced shelf-life of fruits, and with ascorbic acid (250ppm) retention of chlorophyll was the best with minimum fruit weight loss after 8-9 days of storage at room temperature.Cycocel at 500 ppm improve the salt tolerance and fruit yield in okra upto EC 6 mmhos/cm; however seed treatment with 100 ppm cycocel for 8 hrs is found more effective than foliar spray with 500 ppm.

Cauliflower

Treatment of cauliflower seedling with NAA 10ppm as starter solution has been found effective in respect of plant stand in the field and the vegetative growth. Application of GA_4+GA_7 @ 80mg/liter of water shortened the period from transplanting to the harvest. Foliar application of GA+NAA+Mo @ 100ppm+120ppm+0.2% or GA+Urea @ 50ppm+1% increased the yield of cauliflower. Dipping seedlings roots in IBA (0.1 ppm) improves seedling establishment, induces earliness by 10-15 days and increases curd yield. Application of 2, 4-D in combination with BA retards yellowing of curds. Spray of 2, 4-D (100-500 ppm) at 1-7 days before harvest reduces the leaf abscission and weight loss in cauliflower. Post-harvest application of BA (5-20 ppm) has been reported to enhance the shelf-life of curds.

Cabbage

In cabbage, vegetative yield was increased by soaking of seeds in 0.1% boric acid before sowing whereas spraying 50ppm boric acid at flowering enhanced the seed yield. Seedling root dip in GA_3 at 5-10 ppm improves seedling establishment. GA_3(100-1,000ppm) spray resulted in better development of seed. A spray of CCC or SADH (2,500-5,000ppm) increased the low temperature resistance in cabbage. Seed treatment/foliar spray of NAA 0.1% or IBA 0.4% or GA_3 5-10ppm improved head size and yield of cabbage. Spray of 2, 4-D (100-500 ppm) at 1-7 days before harvest reduces the leaf abscission and weight loss in cabbage.

Garlic

Application of PGRs may improve the yield potential of garlic crop. Foliar spray of Ethephon 500ppm or Alar 500ppm at 20-25 days after sowing to increased clove size and yield.Foliar application of NAA 50ppm at 60 and 90 days after planting for increased bulb yield.A foliar spray of GA3 200-400ppm for stimulated formation of lateral buds. Foliar spray of MH 2500ppm on foliage at fortnight before harvesting to controlled sprouting during storage.

Onion

Seed treatment with NAA 100-200ppm or IAA 10ppm improved bulb growth and yield. Seedling treatment with GA 40ppm for improved bulb growth and yield.Foliar spray of MH 2500ppm at one week before bulb digging to check the sprouting during storage.

Cucumber

Plant growth regulators have differential effect on different crops and are being used for modification, sex expression and increasing fruiting in cucurbits. In cucumber, application of Ethrel (150-200ppm), NAA (100ppm), MH (100ppm), boron and molybdenum (3ppm)once at two leaves stage and second at four leaves stage increases the number of female flowers, fruit-set and in turn increases the fruit yield. Growth regulator like GA (1,500-2000ppm) and chemical like silver nitrate (200-300ppm) induce the male flowers on gynoecious cucumber. Application of GA_3 at low concentration 10-15ppm increases femaleness. Foliar spray of NOXA, NAA, 2, 4-D or GA_3 (each at 100 ppm) at pre-anthesis or anthesis has been found promising for inducing parthenocarpic fruit development.

Muskmelon

In muskmelon,soaking of seeds in ethephon at 480mg/liter of water for 24 hours improves germination in muskmelon at low temperature. Application of Ethrel (250ppm) increases the fruiting and in turns the yield. Exogenous application of silver thiosulphate (300-400ppm) induces the male flower in gynoecious muskmelon. These chemicals/plant growth regulators should be applied twice at 2-true-leaf stage and secondly at 4-true-leaf stage.

Watermelon

In watermelon to increases the fruiting and the fruit yield exogenous application of chemicals such as TIBA (25-50ppm), boron (3-4ppm), molybdenum (3-4ppm) and calcium (20-25ppm) are recommended. Fruit yield can also be increased by foliar spray of GA_3 (25-50ppm), ethrel (500ppm), MH (100ppm) and NAA (200ppm). GA_3 (25 ppm) are found most effective in increasing number of female flowers and yield. These chemicals/plant growth regulators must be applied at two-true-leaf stage. Repeat the spray at 4-true-leaf stage.

Bottle Gourd

Fruit set in bottle gourd can be increased by spraying the plant twice at 2 and 4-true-leaf stage with ethrel (100-150ppm), Maleic hydrazide (MH) @400ppm, Triodobenzoic acid (TIBA) @ 50ppm, boron (3-4ppm) and calcium (20ppm). Maleic hydrazide at 400ppm promotes the female flower production and increases fruit set and in turn the yield.

Bitter Gourd

Application of growth regulators at 2-4 leaf stage play an important role in sex expression and sex ratio in bitter gourd. MH at 50-150ppm and CCC at 50-100ppm increases female: male ratio and at a high concentration of 200ppm CCC

it is reduced. Ethrel at 25ppm increases female flowers. GA at 60ppm reduces the ratio of male: female flowers. High level of endogenous GA like substances occur between 45-60 days when the ratio of male: female flowers are low. MH at 150-250ppm when applied at 2 true-leaf stage in variety 'Pusa Do Mousmi' induced the formation of female flowers at the lowest node. Seed treatment with B9 at 3-4ppm for 20 hours gave the highest number of female flowers per plant. Soaking of seeds in Ethrel 20ppm or GA3, MH, silver nitrate at 3-4ppm for 20 hours gave the highest number of female flowers and fruits per plant. Seed treatment with boron 3-4mg/liter or foliar application 3-4mg/liter gave significantly higher yield. Application of cycocel at 250mg/liter gave the highest dry-matter, acetic acid and TSS content and flesh thickness. Foliar spray of NOXA, NAA, 2, 4-D or GA_3 (each at 100 ppm) at pre-anthesis or anthesis has been found promising for inducing parthenocarpic fruit development.

Pumpkin

A growth regulator, Ethrel 250ppm can be applied to increase the female flower production which helps to increase the yield.

Pea

Spraying 15mlof 10 M solution of the growth regulator CCC at the five node stage of development has favorable effect on the growth and yield of crop. Soaking of pea seeds in GA_3 (10ppm) for 12 hours give the highest germination.Foliar application of MH (25 ppm) or CCC (500 ppm) before flowering increases pod yield.

French Bean

Application of growth substances improve the plant growth, flowering, fruit set and pod yield in French bean. Growth regulators like PCPA at 2ppm, L-naphthlyacetamide or B-naphthal acetic acid at 5-25ppm have shown favorable effect on fruit set when sprayed at prevailing temperature when pod set is impaired. GA3 sprayed at 50-200ppm proved effective in improving the crop growth.

Role of plant growth regulators on quality of vegetables and plant tissue culture are described in Table 3 and Table 4, respectively.

Table 3: Effect of Plant Growth Regulators on Quality of Vegetables

Growth Regulator	Concentration (Ppm)	Method of Application	Crop	Effect on Quality
GA_3	15	Foliar spray	Muskmelon	Improve rind thickness
GA_3	5-15	Foliar spray	Cauliflower, cabbage	Increases head or curd size
GA_3	50	Foliar spray	Lettuce and Chinese cabbage	Increases dry matter, protein and ascorbic acid content
PCPA	50	Foliar spray	Tomato	Increased dry matter, sugar and vitamin-C, but reduces acidity
Ethephon	250	Foliar spray	Tomato	Increases TSS
NAA	50-70	Seed treatment	Chilli	Increases amino acid and vitamin-C content in fruits
Mixtallol	1-2	Foliar spray	Potato	Increases starch, reducing sugars, non-reducing sugars, total sugars, and protein
CCC	250	Foliar spray	Potato	Increases TSS and vitamin-C content in tuber

Table 3: Contd.,				
MENA (vapour) + CIPA	5000	Post-harvest dip	Potato	Reduces sprouting and rooting of tuber in storage
2, 4, 5-T	75-125	Pre-harvest spray	Potato	Reduces sprouting and rooting of tuber in storage
MH	2500	Pre-harvest spray	Potato	Reduces sprouting and rooting of tuber in storage
Cytozyme	1%	Foliar spray	Garden pea	Increases vitamin-C, reducing sugars and total sugars

(**Source:** Bahadur and Singh, 2014)

Table 4: Plant Growth Regulators Commonly Used in Plant Tissue Culture

Class	Name	Comments
Auxin	Indole-3-acetic acid (IAA)	Use for callus induction at 10-30 µM. concentration of 1-10 µM can stimulate organogenesis. It is inactivated by light and readily oxidized by plant cells.
	Indole-3-butyric acid (IBA)	Use for rooting shoots regenerated via organogenesis. Either maintains at a low concentration (1-50 µM) throughout the rooting process, or expose to a high concentration (100-250 µM) for 2-10 days and then transfer to hormone free medium.
	2, 4-dichlorophenoxy-acetic acid (2, 4-D)	Most commonly used synthetic auxin for inducing callus and maintaining callus and suspension cells in de-differentiated states. Usually used as sole auxin source (1-50 µM), or in combination with NAA
	Para-chlorophenoxy acetic acid (PCPA) and α-Naphthaleneacetic acid (NAA)	Its use is similar to 2, 4-D. Commonly used either as sole auxin source (2-20 mM for callus induction and growth of callus and suspension cultures; 0.2-2 µM for root induction), or in combination with 2, 4-D
Cytokinin	6-Furfurylaminopurine (kinetin)	Often induced in culture media for callus induction, growth of callus and cell suspensions, and induction of morphogenesis (1-20 µM). Higher concentration (20-25 µM) can be used to induce the rapid multiplication of shoots, axillary/adventitious buds or meristem.
	6-Benzylaminopurine (BAP, BA)	Induced in culture media for callus induction, growth of callus and cell suspensions (0.5-5.0 µM), and for induction of morphogenesis (1-10 µM). More commonly used than kinetin for inducing the rapid multiplication of shoots, bud, or meristem at concentration of 5-50 µM.
	N-Isopentenylamino-purine (2iP)	Less commonly used than kinetin or BAP. For callus induction and growth (2-10 µM), induction of morphogenesis (10-15 µM), or multiplication of shoot, bud, or meristem (30-50 µM) is used.
	Zeatin (Zea)	Seldom used in callus or suspension media. Can be used for induction of morphogenesis (0.05-10 µM). Zea is thermolabile and must not be autoclaved.
Gibberellin	Gibberellic acid (GA_3)	Rarely used in callus or suspension medium (one exception being potato). Can promote shoot growth when added to shoot induction medium at 0.03-14 µM. Also used to enhance development in embryo/ ovule cultures (0.3-48 µM). GA_3 is thermolabile and must not be autoclaved.
Abscisic acid	Abscisic acid (ABA)	Used at concentrations of 0.4-10 µM to prevent precocious germination, and promote normal development of somatic embryos.

(**Source:** Bahadur and Singh, 2014)

Precautions in Growth Regulator Application

- Growth regulators should be sprayed preferably in the afternoon.
- Avoid spraying in windy hours.
- Spray should be uniform and wet both the surface of leaf.
- Add surfactant or adhesive materials like Teepol and Tween-20 with growth regulators @ 0.5-1.0 ml/l solution.
- Use growth substances at an appropriate stage of plant growth.
- Chemical should be completely dissolved before use.
- Use always fresh solution of plant growth regulators.
- Solution should be always being prepared in distilled water only.
- Fine spray can be ensured by hand automizer. It is most economical and effective method of spray.
- Wash the machine or pump after each spraying.
- Repeat the spray within 8 hours, if chemical is washed out due to rain.

CONCLUSIONS

Thus, it can be concluded from this review, use of plant growth regulator in vegetables has been found beneficial for improve yield, quality, synchronization in flowering, earliness, cold and high temperature fruit setting, sex modification, increases post-harvest life, and develop resistance to biotic and abiotic stresses. Those are also very effective for induction of male sterility in vegetable crops.

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